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None

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(54) **Cylinder liner for a reciprocating piston engine and method of producimg such a cylinder liner**

(57) A cylinder liner sealed into a reciprocating piston engine and comprises a strongly supereutectic aluminium/silicon alloy of a specified composition which is free of melt-independent particles of hard material and which is composed in such a way that fine silicon primary crystals and intermetallic phases automatically form from the melt as hard particles. By means of spray compaction, a blank is allowed to grow from finely sprayed melt droplets, with a fine distribution of the hard particles being produced by the setting of small melt droplets. The blank can then be formed by cold extrusion to give a shape approximating the cylinder lining. After subsequent premachining, the face is fine machined, subsequently honed in at least one stage and then the hard particles lying at the face are exposed, forming plateau areas of the particles which project above the remaining surface of the base microstructure of the alloy. The mechanical exposure of the primary crystals or particles is carried out in the manner of a honing process using felt strips which are cylindrically shaped on the outside and a slurry of SiC particles in honing oil.

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Fig. 1

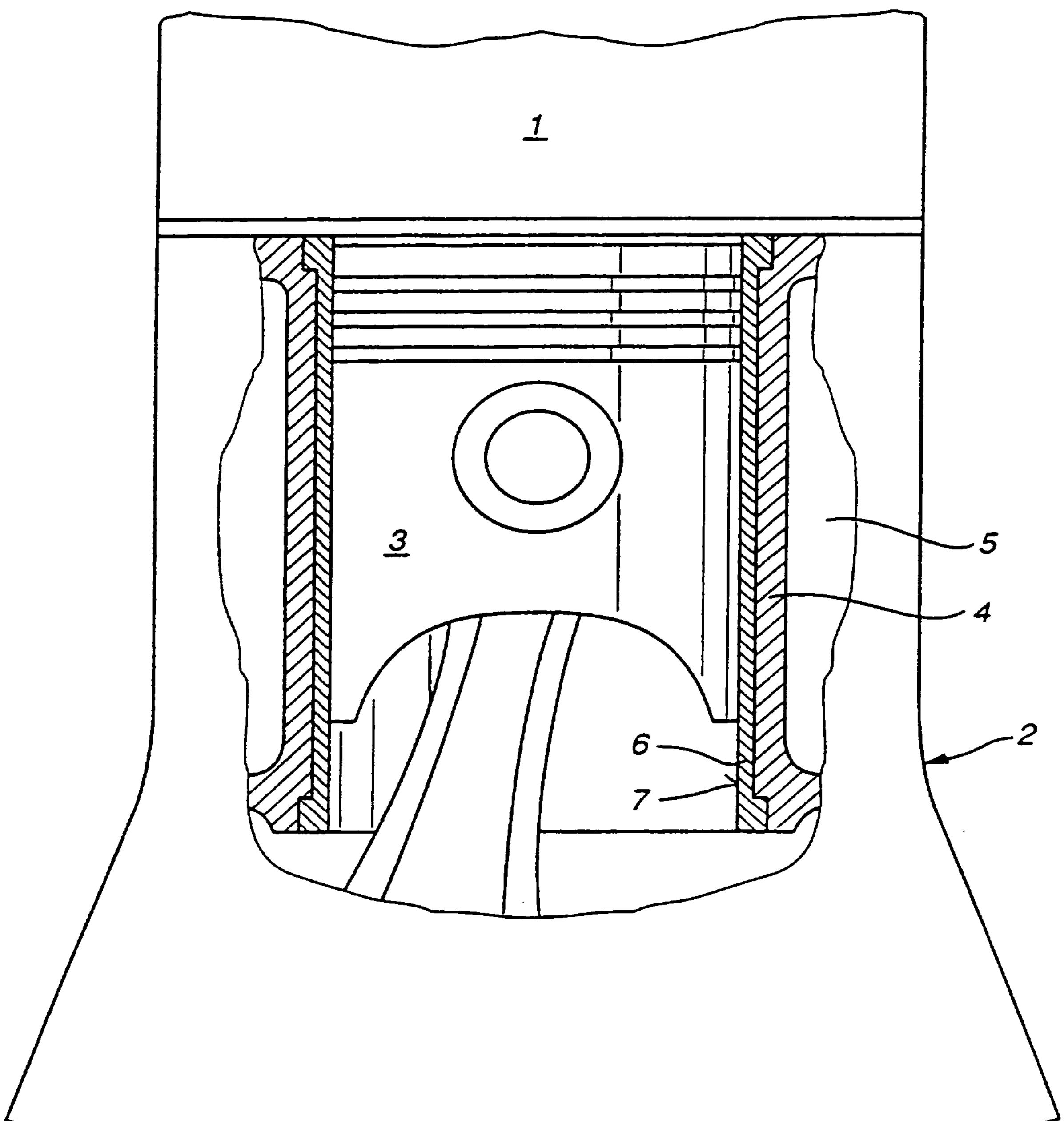


Fig. 2

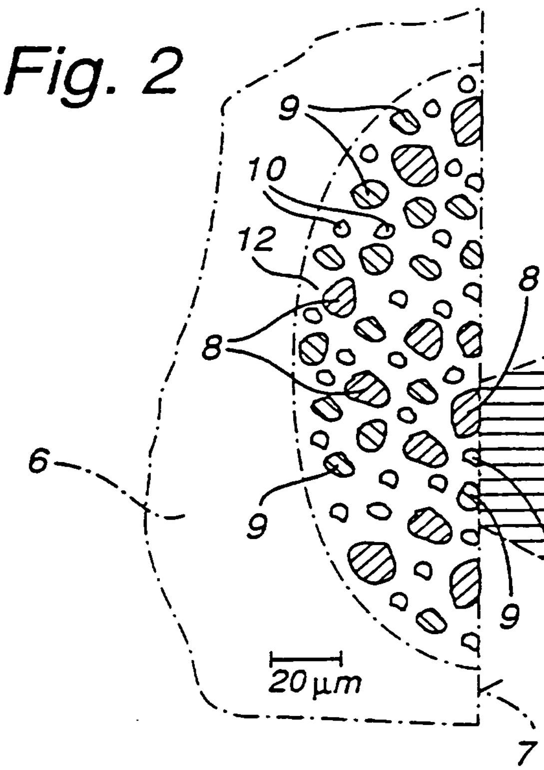
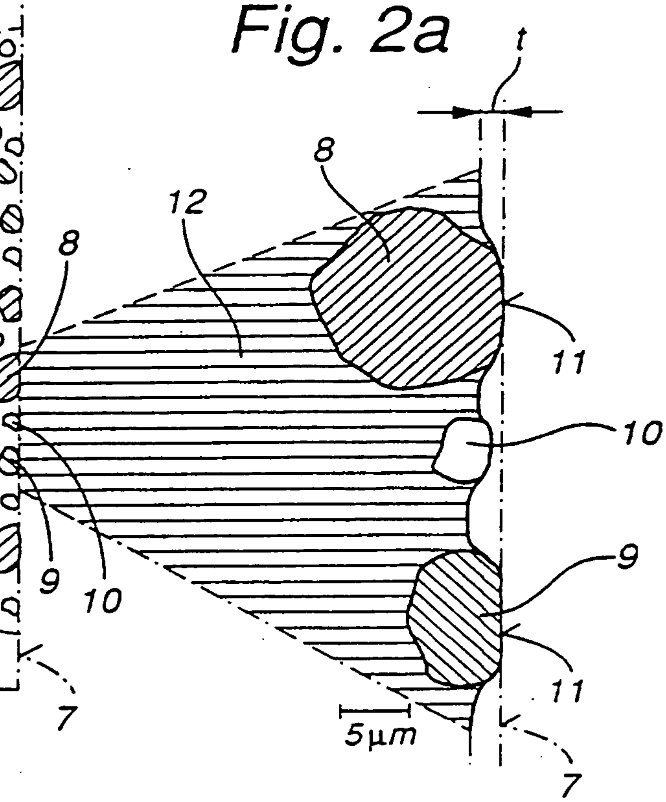


Fig. 2a



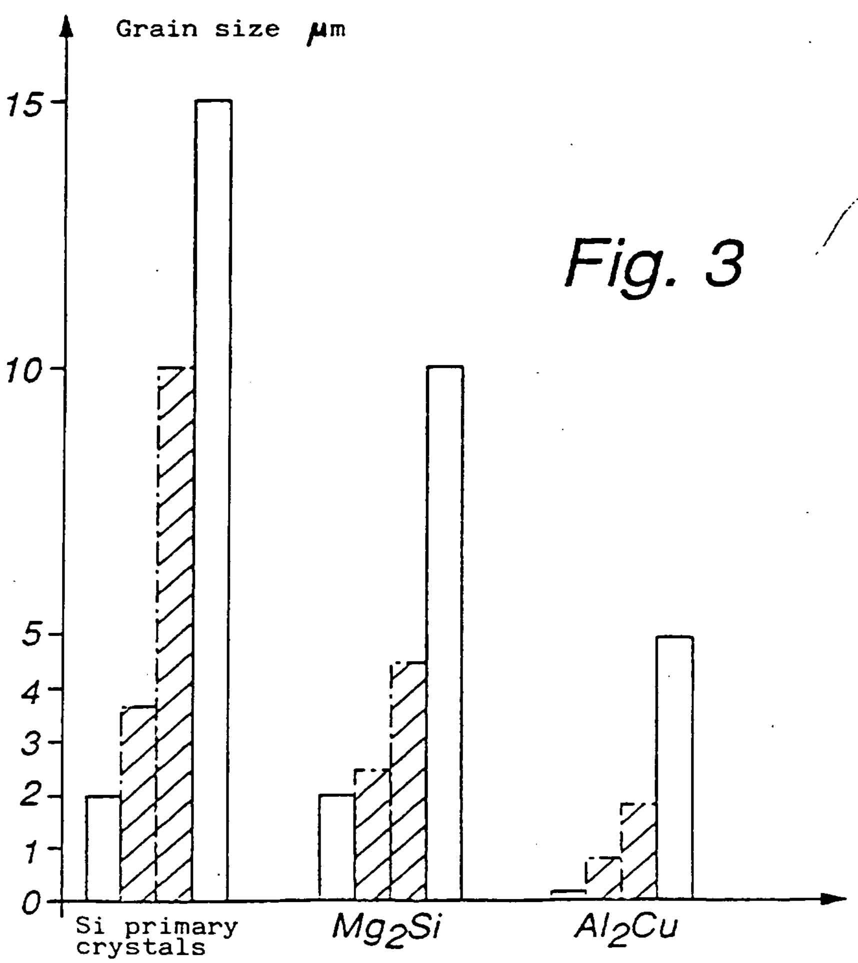
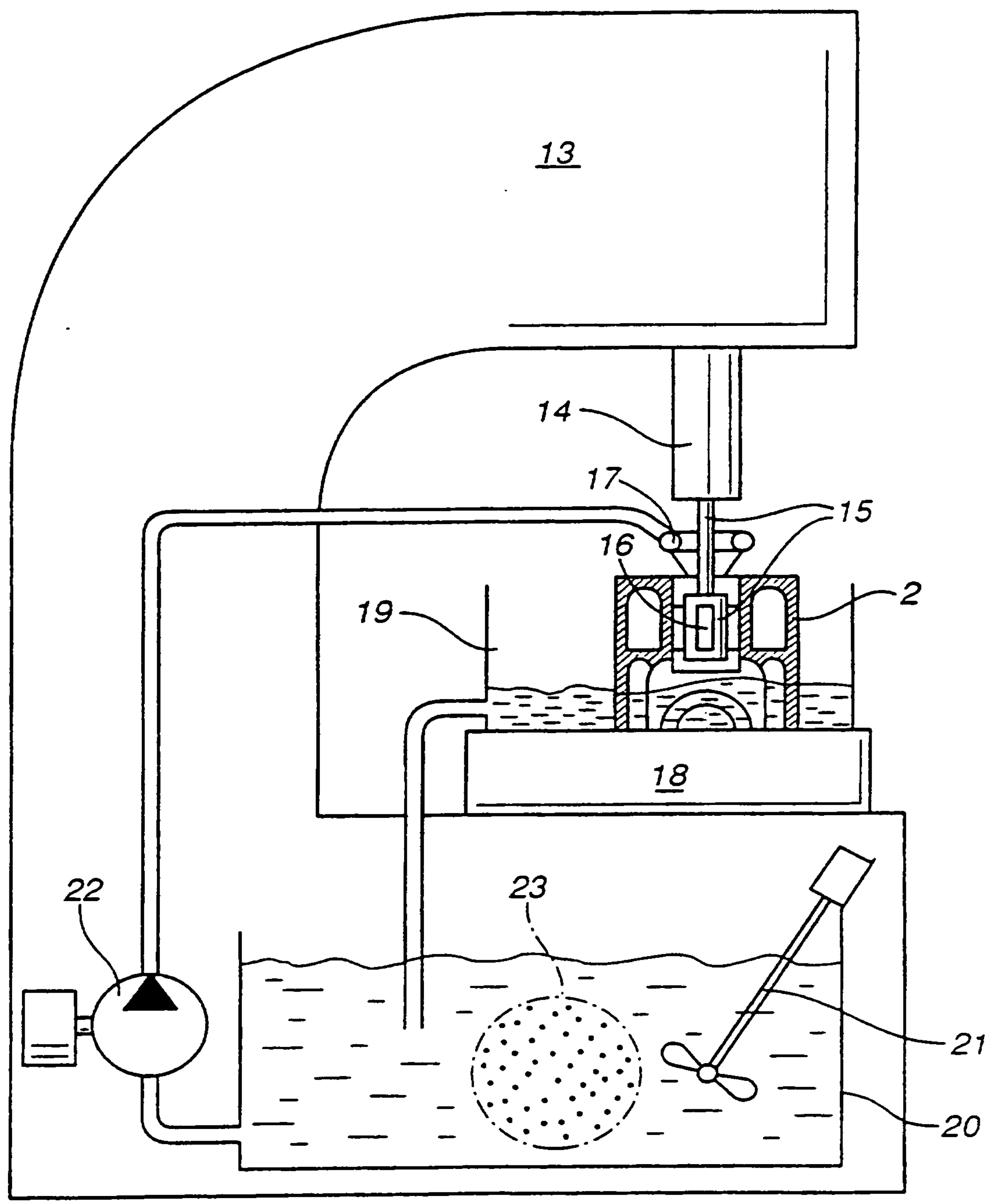


Fig. 3

Fig. 4



Cylinder liner for a reciprocating piston engine and method of producing such a cylinder liner

The invention relates to a cylinder liner comprising a supereutectic aluminium/silicon alloy for sealing into a reciprocating piston engine, and to a method of forming such a liner.

EP 367 229 A1 discloses a cylinder liner which is produced from metal powder and mixed-in graphite particles (from 0.5 to 3%; with a particle diameter at most 10 μm or less, measured in a plane perpendicular to the cylinder axis) and particles of hard material without sharp edges (from 3 to 5%; particle diameter at most 30 μm, on average 10 μm or less), in particular aluminium oxide. The metal powder is first produced on its own, i.e. without mixed-in nonmetallic particles, by air atomization of a supereutectic aluminium/silicon alloy having the following composition - the remainder being aluminium (figures in % by weight based on the total metal content of the alloy, i.e. without the particles of hard material and amounts of graphite foreign to the melt):

Silicon	from 16 to 18%,
Iron	from 4 to 6%,
Copper	from 2 to 4%,
Magnesium	from 0.5 to 2% and
Manganese	from 0.1 to 0.8%.

The metal powder is mixed with nonmetallic particles and this powder mixture is pressed at about 2000 bar to give a preferably tubular body. This powder-metallurgically produced blank is inserted into a soft aluminium tube of corresponding shape and the double-layer tube thus obtained is jointly sintered and shaped in an extrusion process, preferably at elevated temperatures, to give a tubular blank from which the individual cylinder liners can be produced. The embedded particles of hard material are intended to give the cylinder liner good wear resistance, while the graphite particles serve as dry

lubricant. To avoid oxidation of the graphite particles, the hot extrusion should take place with exclusion of oxygen. There is also the danger of the graphite reacting with the silicon at high processing temperatures and forming hard SiC on the surface, which impairs the dry-lubrication properties of the embedded graphite particles. Since the powder mixture is always more or less complete, the local occurrence on the surface of the workpiece of more or less great concentration fluctuations of particles of hard material and/or of graphite particles can never be entirely ruled out. Owing to the embedded particles of hard material, the hot-pressing die wears relatively quickly, because the particles of hard material, despite their rounded edges, still have a strong abrasive action in any case, only a partial rounding of the edges on the particles formed by crushing can be achieved with justifiable effort. The subsequent machining of the face of the cylinder liner is also associated with high tool wear and thus with high tool costs. The particles of hard material exposed on the face have sharp edges after the surface machining and cause relatively high wear of the piston and the piston rings, so that these have to be made of a wear-resistant material or be provided with an appropriately wear-resistant coating. Overall, the known cylinder liner is not only relatively expensive because of the starting materials with a plurality of separate components, but the high tool costs associated with the plastic forming and the cutting machining drive up the costs per item. Apart from this, the way in which the known cylinder liners are produced from a heterogeneous powder mixture involves the danger of inhomogeneities which may result in impairment of their function, and thus in rejects, but in any case require complex quality control. In addition, it requires complicated piston constructions in engine operation, which make the entire reciprocating piston engine more expensive.

Mention may also be made of US-A 4 938 810 which likewise discloses a powder-metallurgically produced

cylinder liner. In that document, a great number of alloy examples are provided and measurement and operating data of the cylinder liners produced therewith are also given. The silicon contents of the examples provided are in the range from 17.2 to 23.6%, although in this respect the claim of this document recommends a wider range of from 10 to 30%, which extends into the subeutectic region. At least one of the metals nickel, iron or manganese should likewise be present in the alloy, indeed at least to the extent of 5% or (iron) to the extent of at least 3%. As a representative, mention is here made only of an alloy composition in % by weight, the remainder is aluminium; zinc and manganese contents are not specified, from which it can be concluded that these metals should not be present apart from traces:

Silicon:	22.8%,
Copper:	3.1%,
Magnesium:	1.3%,
Iron:	0.5% and
Nickel:	8.0%.

The nickel content in the alloy example given is very high. A blank for a cylinder liner is hot-extruded from the powder mixture.

Finally, mention may also be made of US-A 4 155 756 which is concerned with the same subject. In that document, inter alia, the following composition of a powder-metallurgically produced cylinder liner is given as an example of others - remainder aluminium:

Silicon:	25%,
Copper:	4.3%,
Magnesium:	0.65% and
Iron:	0.8%.

The present invention seeks to improve a cylinder liner in respect of wear resistance and lubricating oil consumption, with the danger of wear of the piston being likewise reduced; in reducing the lubricating oil consumption, the main interest is less in the lubricating oil itself but rather in its combustion residues -

essentially hydrocarbons which unfavourably pollute the exhaust gas emitted from the internal combustion engine.

According to the present invention there is provided a cylinder liner sealed into a reciprocating piston engine and comprising a supereutectic aluminium/silicon alloy, comprising;

an aluminium/silicon alloy which, is free of melt-independent particles of hard material, is composed as follows in the two alternatively usable alloy types A and B, with the figures referring to the content in % by weight:

<u>Alloy A:</u>

Silicon from 23.0 to 28.0%,
Magnesium from 0.80 to 2.0%,
Copper from 3.0 to 4.5%,
Iron maximum of 0.25%,
Manganese, nickel and zinc maximum in each case of 0.01%,
remainder aluminium or

<u>Alloy B:</u>

Silicon from 23.0 to 28.0%,
Magnesium from 0.80 to 2.0%,
Copper from 3.0 to 4.5%,
Iron from 1.0 to 1.4%,
Nickel from 1.0 to 5.0%,
Manganese and zinc maximum in each case of 0.01%, and the remainder aluminium, wherein in the cylinder liner, silicon primary crystals and intermetallic phases are present in the following grain sizes, with the figures referring to the mean grain diameter in μm:

Si primary crystals: from 2 to 15 μm,
Al_2Cu phase: from 0.1 to 5.0 μm,
Mg_2Si phases: from 2.0 to 10.0 μm,
and wherein out of the fine-machined face of the cylinder liner, silicon primary crystals and particles of intermetallic phases embedded at the surface are exposed, with the exposed plateau areas of the primary crystals or particles going over at their edges to the base alloy material in a spherical or rounded manner.

Owing to the specific alloy composition of the material for the cylinder liner, silicon primary crystals and intermetallic phases are formed directly from the melt; the mixing in of separate hard particles can therefore be omitted. Furthermore, the spray compaction of the alloy, which can readily be mastered in methodology and is comparatively inexpensive, is used together with subsequent, energy-saving cold extrusion of the blank. This method gives a particularly low oxidation of the droplet surfaces and a particularly low porosity of the liner. The alloy compositions A and B mentioned are optimized for use with iron-coated pistons (alloy A) or with uncoated aluminium pistons (alloy B). The hard particles formed from the melt possess, on the one hand, a high hardness and give the face good wear resistance, on the other hand these hard particles formed from the melt do not seriously impede the machining of the material, so that the face is sufficiently readily machinable. Owing to the formation of the primary crystals and intermetallic phases in each melt droplet sprayed onto and subsequently solidifying on the growing blank, the process results in a very uniform distribution of the hard particles in the workpiece. The particles formed from the melt are also less angular and tribologically less aggressive than crushed particles. Moreover, the metallic hard particles formed from the melt are more intimately embedded in the basic alloy microstructure than are nonmetallic crushed particles which have been mixed in, so that the danger of crack formation at the hard material boundaries is less. In addition, the hard particles formed from the melt display a better running-in behaviour and a lower abrasive aggressivity towards the piston and its rings, so that higher lifetimes result or, with acceptance of conventional lifetimes, less complex designs of the piston can be permitted.

Advantageous embodiments of the invention are illustrated below with the aid of the drawings; in the drawings:

Fig. 1 shows a partially sectioned view of a reciprocating piston engine having a sealed-in cylinder liner,

Fig. 2 shows a greatly magnified part of a cross-section through a region of the cylinder liner close to the surface, taken parallel to a cylinder wall line,

Fig. 2a shows a further enlargement of a detail of Figure 2,

Fig. 3 is a bar graph showing the particle sizes of the various hard particles formed from the melt and

Fig. 4 shows a modified honing machine for mechanically exposing the hard particles out of the surface of the cylinder liner.

The reciprocating piston engine partly shown in Figure 1 comprises a diecast crankcase 2 in which there is arranged the cylinder wall 4 for accommodating a cylinder liner 6 in which a piston 3 is installed so as to be able to move up and down. On top of the crankcase 2 there is attached a cylinder head 1 fitted with the devices for charge change and charge ignition. Within the crankcase there is provided, around the cylinder wall 4, a hollow space for forming a water jacket 5 for cylinder cooling.

The cylinder liner 6 is made as an individual part by a method described in detail below of a supereutectic composition, on the subject of which further details will likewise be given below, then is sealed as a blank part into the crankcase 2 and is machined together with the crankcase. For this purpose, inter alia, the face of the cylinder liner is first roughly premachined and subsequently fine machined by means of boring or turning. The face 7 is subsequently honed in at least one stage. After honing, the particles lying in the face which are harder than the base microstructure of the alloy, such as silicon crystals and intermetallic phases, are exposed out of the face in such a way that plateau surfaces of the particles project above the remaining surface of the base microstructure of the alloy.

To improve the cylinder liners in respect of the wear resistance and the lubricating oil consumption and thus to improve the emission of hydrocarbons by the internal

combustion engine, the invention provides a series of measures which jointly act together for this purpose.

Firstly, mention should here be made of optimization of the composition of the alloy, where two alternative types of alloy have here been found to be optimal, with one alloy type A being recommended for use together with iron-coated pistons and the other alloy type B being optimized in connection with uncoated aluminium pistons. The percentages below are by weight. The alloy A has the following composition:

Silicon	from	23.0 to 28.0%,	preferably about 25%,
Magnesium	from	0.80 to 2.0%,	preferably about 1.2%,
Copper	from	3.0 to 4.5%,	preferably about 3.9%,
Iron max.		0.25%	

Manganese, nickel and zinc max. 0.01% and the remainder aluminium.

The alloy B for operation together with uncoated aluminium pistons has the same composition as the alloy A in respect of the proportions of silicon, copper, manganese and zinc; only the iron and nickel contents are somewhat higher, namely

Iron	from 1.0 to 1.4% and
Nickel	from 1.0 to 5.0%.

A melt of the aluminium/silicon alloy is finely sprayed into an oxygen-free atmosphere and the mist of melt is deposited to give a growing body, first producing a knob containing fine-grained silicon primary crystals 8 and intermetallic phases 9 and 10, with the intermetallic phases being those containing magnesium and silicon (Mg_2Si) and containing aluminium and copper (Al_2Cu). The atomized melt is very quickly cooled in a jet of nitrogen, with cooling rates in the range of 10^5 K/sec being achieved. This so-called spray compacting enables production of a microstructure having a very narrow grain size distribution with a range of about ± 5 ... 10 µm about a mean value, with the mean value being able to be adjusted within a relatively wide particle size range from about 7 to 200 µm. A very fine

grain setting, particle size of from 2 to 10 μm, is used here, so that a correspondingly fine microstructure having a fine and uniform silicon distribution is formed. Each powder particle contains all the alloy constituents. The powder particles are sprayed onto a rotating plate on which the knob mentioned having a diameter of, for example, 300 or 1000 mm grows. This depends on the design of the apparatus. Subsequently, the knobs have to be extruded on an extruder to form tubes. It is also conceivable that the knob is not allowed to grow axially on a rotating plate, but the atomized melt is allowed to grow radially on a rotating cylinder, so that an essentially tubular preproduct is formed.

During spraying, the melt is so finely atomized that the silicon primary crystals 8 and the intermetallic phases 9 and 10 which form in the growing knob have very small grain sizes of the following dimensions:

Si primary crystals: from 2 to 15 μm, preferably from 4 to 10 μm,

Al_2Cu phase: from 0.1 to 5.0 μm, preferably from 0.8 to 1.8 μm,

Mg_2Si phase: from 2.0 to 10.0 μm, preferably from 2.5 to 4.5 μm.

This fine grained nature gives, on the one hand, a finely dispersed distribution of the hard particles within the base microstructure of the alloy and a homogeneous material is obtained. Since a single melt is atomized, no mixing inhomogeneities can be formed. The compacting of the atomized melt droplets also results in a very intimate bonding of the droplets to one another and in substantial avoidance of porosity.

The method of spray compacting aluminium alloys is known per se and is intended to be used here only as an advantageous procedure. The extrusion of knobs produced in this way to give tubes from which individual liners can then be cut is likewise known per se. For this reason, no further details of these methods shall be given here.

The blanks of the cylinder liner produced in such a way and possibly brought to a certain further-processing dimension by machining are sealed into a crankcase comprising a readily castable aluminium alloy, with a pressure diecasting process being preferably recommended here. For this purpose, the prefabricated cylinder liners to be sealed in are pushed onto a guide pin with the diecasting mould open, the mould is closed and the diecasting material is injected. Owing to the fast cooling time and the ability to cool the cylinder liner to be sealed in via the guide pin, there is no danger of the material of the cylinder liner being thermally affected in an uncontrolled manner by the melt of the diecast part. The alloy used for diecasting is subeutectic and therefore readily processable by casting. Moreover, the thermal expansion of the alloy of the diecast part on the one hand and the cylinder liner on the other hand is approximately equal, so that no uncontrolled thermal stresses occur between the two.

After sealing the cylinder liner into the crankcase, this is machined on the appropriate surfaces, particularly on the faces 7 of the cylinder liner 6. These machining processes - mention is here made only of boring and honing - are also known per se, for which reason no further details on them will be given here. Subsequent to the honing, the silicon primary crystals 8 and the particles of intermetallic phases 9 and 10 embedded at the surface have to be exposed. This exposure is usually carried out chemically by means of etching, which is not only time-consuming, but is also associated with a certain pollution of the workplace environment by evaporation of etching liquid. In addition, a certain inhomogeneity is unavoidable in etching, because the etching conditions are not completely uniform everywhere. For this reason, a certain minimum exposure depth has to be sought, so as to obtain, in every case, a certain minimum exposure depth even at the unfavourable places. The time expended on etching, the safety precautions in the workplace and the ongoing

operation costs, primarily costs for chemicals, waste water and disposal, add up to quite considerable amounts per cylinder liner. The present invention here takes another route: the primary crystals 8 and particles 9 and 10 embedded in the face are mechanically exposed by a grinding or polishing process using compliant, shaped polishing or grinding bodies 16. This avoids not only the disadvantages and costs of etching, but also gives, in particular, use advantages and functional advantages for the face 7 of the cylinder liner, further details on which will be given below. The costs incurred by the mechanical exposure per cylinder liner are not higher than the costs of a honing process.

In connection with the mechanical exposure, further details should be given on the honing machine shown in Fig. 4 which is also to be used in this polishing process. The honing machine 13 shown there has a movable machine table 18 on which the crankcase 2 is accommodated in a pan 19. Above the machine table 18 there is arranged at least one vertical honing spindle 14 into which is fitted a honing tool 15 which can be lowered into a cylinder bore of the crankcase. The special thing about the honing machine is, on the one hand, that the honing tool 15 is fitted not with hard honing stones, but is fitted on its circumference with a plurality of axially orientated felt strips 16 which, owing to the felt being compliant, automatically give a cylindrical fit to the inner surface of the cylinder liner. These serve as shape-matched polishing or grinding bodies. The construction of the honing tool includes metal abrasive carriers which are fitted in the honing tool so as to be radially movable and which can be pressed with adjustable force against the inner surface of the cylinder liner. The metal abrasive carriers were planar, i.e. not cylindrical, on their side facing radially outwards. Matching cut pieces of a felt mat having a thickness of 9 mm were in each case glued onto these flat surfaces, with the felt pieces glued on not being formed on the outside in the manner of a cylindrical

surface. Rather, the required cylindrical shape resulted automatically on commencing the honing-like polishing or grinding under the pressure of the felt pieces against the inner surface of the cylinder liner. The felt material is a felt designated as Stückfilz Tm 30 - 9, DIN 61206; a felt designated as Stückfilz Tm 32 - 9, DIN 61206 would also certainly be suitable. The individual data in the designation have the following meanings:

m → mixed,

30 → bulk density of 0.3 g/cm³ or 32 → bulk density of 0.32 g/cm³,

9 → 9 mm in thickness.

The hardness of the felt pieces used was M6 (medium 6) in accordance with DIN 61200; in the case of Stückfilz Tm 32 - 9, DIN 61206, a hardness according to DIN 61200 with the designation F1 (firm 1) could be recommended.

Since this mechanical exposure is also carried out in the presence of an abrasive, amorphous grinding or polishing medium having particles of hard material present therein, provisions are also made on the honing machine 13 for supplying the grinding medium. For this purpose, a reservoir 20 for holding a slurry 23 of fine particles of hard material, preferably silicon carbide particles in honing oil, is placed by the machine. To avoid sedimentation of the particles of hard material, the reservoir is provided with a stirrer 21. A circulation pump 22 conveys the slurry from the reservoir 20 to an annular sprinkling head 17 which goes around the honing tool above the cylinder liner and supplies plenty of grinding fluid to this. During the mechanical exposure, the rotating honing tool performs, in a known manner, an axially oscillating up and down movement so that all parts of the face 7 are reached by the felt strips 16. The honing tool is, in a known manner, configured in such a way that the felt strips can be pressed with an adjustable pressure against the face 7. The mechanical exposure is preferably carried out with application of a pressure of from about 3 to 5 bar, preferably about 4 bar.

By means of this method of machining, the material of the base alloy material located between the individual harder particles at the surface is removed to some extent, so that the harder particles project above the abraded base material 12 with a plateau area 11. The measure t represents the exposure depth. In this method of operation, the edges of the plateau areas 11 are rounded so that they gently go over into the base alloy material 12. This configuration of the plateau areas 11 is very advantageous for the piston or the piston rings sliding over them, because it is tribologically not very aggressive in comparison with the sharp-edged particles of hard material in the case of chemical exposure. The measure of the exposure depth t can, apart from the pressing force of the felt strips, be determined primarily by the duration of the honing-like process during mechanical exposure. This is because with increasing time of the exposure process the plateau areas 11 are increasingly rounded and abraded into a dome-like shape. It has therefore been found to be advantageous to carry out the mechanical exposure process in the manner described for from about 20 to 60 seconds, preferably about 40 seconds. This gives an exposure depth of from about 0.2 to 0.3 μm. In any case, on this exposure depth there is superimposed a surface roughness which is at least of the same order of magnitude if not even greater, but this is not shown in Fig. 2a. The roughness of the surface is essentially determined by the grain size of the particles of hard material in the slurry 23; the roughness values on machined cylinder faces are in the range from 0.7 to 1.0 μm. These roughness values and the low exposure depth enable very low oil consumptions and thus very low emissions of hydrocarbons to be achieved. In addition, the wear resistance and the sliding properties of the cylinder liners thus produced are excellent.

Claims

1. A cylinder liner sealed into a reciprocating piston engine and comprising a supereutectic aluminium/silicon alloy, comprising;

an aluminium/silicon alloy which, is free of melt-independent particles of hard material, is composed as follows in the two alternatively usable alloy types A and B, with the figures referring to the content in % by weight:

Alloy A:

Silicon from 23.0 to 28.0%,
Magnesium from 0.80 to 2.0%,
Copper from 3.0 to 4.5%,
Iron maximum of 0.25%,
Manganese, nickel and zinc maximum in each case of 0.01%,
remainder aluminium or

Alloy B:

Silicon from 23.0 to 28.0%,
Magnesium from 0.80 to 2.0%,
Copper from 3.0 to 4.5%,
Iron from 1.0 to 1.4%,
Nickel from 1.0 to 5.0%,
Manganese and zinc maximum in each case of 0.01%, and the remainder aluminium, wherein in the cylinder liner, silicon primary crystals and intermetallic phases are present in the following grain sizes, with the figures referring to the mean grain diameter in μm:

Si primary crystals: from 2 to 15 μm,
Al_2Cu phase: from 0.1 to 5.0 μm,
Mg_2Si phases: from 2.0 to 10.0 μm,
and wherein out of the fine-machined face of the cylinder liner, silicon primary crystals and particles of intermetallic phases embedded at the surface are exposed, with the exposed plateau areas of the primary crystals or particles going over at their edges to the base alloy material in a spherical or rounded manner.

2. A cylinder liner according to claim 1, wherein the silicon content of alloy types A and B is 25%, the magnesium content 1.2% and the copper content 3.9%.

3. A cylinder liner according to claim 1 or 2, wherein the grain size of the Si primary crystals is from 4.0 to 10.0 μm, the Al_2Cu phase from 0.8 to 1.8 μm, and the Mg_2Si phases from 2.5 to 4.5 μm.

4. A cylinder liner according to Claim 1, 2 or 3 wherein the exposure depth of the plateau areas of the primary crystals or particles compared with the surrounding base alloy material is from about 0.2 to 0.3 μm.

5. A cylinder liner according to any one of Claims 1 to 4, wherein the exposed primary crystals or particles have, after exposure, a roughness of Rz = 0.7 to 1.0 μm on their exposed plateau area.

6. A method of producing a cylinder liner comprising a supereutectic aluminium/silicon alloy, in which the face thereof is first roughly premachined and then fine machined by means of boring or turning and subsequently honed in at least one stage and in which the particles lying in the face which are harder than the base microstructure of the alloy, such as silicon crystals and/or intermetallic phases, are then exposed in such a way that plateau areas of the particles project above the remaining surface of the base microstructure of the alloy, comprising mechanically exposing primary crystals or particles embedded at the surface out of the face of the cylinder liner by means of a grinding or polishing process using at least one compliant shaped polishing or grinding body and an abrasive, amorphous grinding or polishing medium containing particles of hard material whose grain size is less than or at most the same as the desired roughness.

7. A method of producing a cylinder liner comprising a supereutectic aluminium/silicon alloy, in which this is first produced on its own as a tubular blank and is then sealed into a supporting crankcase of a reciprocating piston engine, in which furthermore, in the sealed-in state of the cylinder liner, the face thereof is roughly premachined and then fine-machined by means of boring or turning and is subsequently honed in at least one stage and in which the particles lying in the face which are harder than the base microstructure of the alloy, such as silicon crystals and intermetallic phases, are then exposed in such a way that plateau areas of the particles project above the remaining surface of the base microstructure of the alloy, comprising the following features:

- the material used for the cylinder liner is alternatively one of the two following aluminium/silicon alloys A and B which are free of melt-independent particles of hard material, with the figures referring to the content in % by weight:

  Alloy A:

  Silicon from 23.0 to 28.0%,
  Magnesium from 0.80 to 2.0%,
  Copper from 3.0 to 4.5%,
  Iron maximum of 0.25%,
  Manganese, nickel and zinc maximum in each case of 0.01%, and the
  remainder aluminium, or

  Alloy B:

  Silicon from 23.0 to 28.0%,
  Magnesium from 0.80 to 2.0%,
  Copper from 3.0 to 4.5%,
  Iron from 1.0 to 1.4%,
  Nickel from 1.0 to 5.0%,
  Manganese and zinc maximum in each case of 0.01%, and the remainder aluminium,

- by fine spraying of the melt of the aluminium/silicon alloy and deposition of the mist of melt to give a

growing body, there is first produced a knob containing fine-grained silicon primary crystals and intermetallic phases and this is formed by extrusion to give a tubular semi-finished part from which the cylinder liner is produced,

- during spraying, the melt is so finely atomized that the silicon primary crystals and intermetallic phases which form in the growing knob are obtained in grain sizes having the following dimensions, with the figures referring to the mean grain diameter in μm:
  Si primary crystals: from 2 to 15 μm,
  Al_2Cu phase: from 0.1 to 5.0 μm,
  Mg_2Si phase: from 2.0 to 10.0 μm,
- the exposure of the primary crystals and particles embedded at the surface out of the face of the cylinder liner, which has already been fine machined on its face, is carried out mechanically by a grinding or polishing process using at least one compliant shaped polishing or grinding body and an abrasive, amorphous grinding or polishing medium containing particles of hard material whose particle size is less than or at most the same as the desired roughness.

8. A method according to Claim 6 or 7, wherein the mechanical exposure of the primary crystals and particles is carried out in the manner of a honing process using felt strips having an outer cylindrical shape and a slurry of particles of hard material

9. A method according to claim 8, wherein the said hard particles in the slurry are SiC particles in honing oil.

10. A method according to Claim 8 or 9, wherein the mechanical exposure of the primary crystals and particles is carried out with the felt strips being pressed against the contact point at a pressure of from 3 to 5 bar.

11. A method according to Claim 10, wherein the mechanical exposure of the primary crystals and particles is carried out at a pressure of 4 bar.

12. A method according to Claim 8, wherein the honing-like process for the mechanical exposure of the primary crystals and particles is carried out for from about 20 to 60 seconds

13. A method according to Claim 8, wherein the honing-like process for the mechanical exposure of the primary crystals and particles is carried out for about 40 seconds.

14. A method according to claim 7, wherein the silicon content of alloy types A and B is 25%, the magnesium content 1.2% and the copper content 3.9%, and the grain size of the Si primary crystals is from 4.0 to 10.0 μm, the Al_2Cu phase from 0.8 to 1.8 μm, and the Mg_2Si phases from 2.5 to 4.5 μm.

15. A cylinder liner sealed into a reciprocating piston engine substantially as described herein with reference to and as illustrated in the accompanying drawings.

16. A method of forming a cylinder liner according to claim 15.

Amendments to the claims have been filed as follows

1. A cylinder liner sealed into a reciprocating piston engine and comprising a supereutectic aluminium/silicon alloy, comprising;

an aluminium/silicon alloy which, is free of melt-independent particles of hard material, is composed as follows in the two alternatively usable alloy types A and B, with the figures referring to the content in % by weight:

Alloy A:

Silicon	from 23.0 to 28.0%,
Magnesium	from 0.80 to 2.0%,
Copper	from 3.0 to 4.5%,

Iron maximum of 0.25%,

Manganese, nickel and zinc maximum in each case of 0.01%, remainder aluminium or

Alloy B:

Silicon	from 23.0 to 28.0%,
Magnesium	from 0.80 to 2.0%,
Copper	from 3.0 to 4.5%,
Iron from	1.0 to 1.4%,
Nickel	from 1.0 to 5.0%,

Manganese and zinc maximum in each case of 0.01%, and the remainder aluminium, wherein in the cylinder liner, silicon primary crystals and intermetallic phases are present in the following grain sizes, with the figures referring to the mean grain diameter in μm:

Si primary crystals: from 2 to 15 μm,

Al_2Cu phase: from 0.1 to 5.0 μm,

Mg_2Si phases: from 2.0 to 10.0 μm,

and wherein out of the fine-machined face of the cylinder liner, silicon primary crystals and particles of intermetallic phases embedded at the surface are exposed, with the exposed plateau areas of the primary crystals or particles going over at their edges to the base alloy material in a spherical or rounded manner.

2. A cylinder liner according to claim 1, wherein the silicon content of alloy types A and B is 25%, the magnesium content 1.2% and the coppper content 3.9%.

3. A cylinder liner according to claim 1 or 2, wherein the grain size of the Si primary crystals is from 4.0 to 10.0 μm, the Al_2Cu phase from 0.8 to 1.8 μm, and the Mg_2Si phases from 2.5 to 4.5 μm.

4. A cylinder liner according to Claim 1, 2 or 3 wherein the exposure depth of the plateau areas of the primary crystals or particles compared with the surrounding base alloy material is from about 0.2 to 0.3 μm.

5. A cylinder liner according to any one of Claims 1 to 4, wherein the exposed primary crystals or particles have, after exposure, a roughness of Rz = 0.7 to 1.0 μm on their exposed plateau area.

6. A method of producing a cylinder liner comprising a supereutectic aluminium/silicon alloy, in which this is first produced on its own as a tubular blank and is then sealed into a supporting crankcase of a reciprocating piston engine, in which furthermore, in the sealed-in state of the cylinder liner, the face thereof is roughly premachined and then fine-machined by means of boring or turning and is subsequently honed in at least one stage and in which the particles lying in the face which are harder than the base microstructure of the alloy, such as silicon crystals and intermetallic phases, are then exposed in such a way that plateau areas of the particles project above the remaining surface of the base microstructure of the alloy, comprising the following features:

- the material used for the cylinder liner is alternatively one of the two following aluminium/silicon alloys A and B which are free of melt-independent particles of hard material, with the figures referring to the content in %

by weight:

<u>Alloy A:</u>

Silicon	from 23.0 to 28.0%,
Magnesium	from 0.80 to 2.0%,
Copper	from 3.0 to 4.5%,

Iron maximum of 0.25%,

Manganese, nickel and zinc maximum in each case of 0.01%, and the remainder aluminium, or

<u>Alloy B:</u>

Silicon	from 23.0 to 28.0%,
Magnesium	from 0.80 to 2.0%,
Copper	from 3.0 to 4.5%,
Iron	from 1.0 to 1.4%,
Nickel	from 1.0 to 5.0%,

Manganese and zinc maximum in each case of 0.01%, and the remainder aluminium,

- by fine spraying of the melt of the aluminium/silicon alloy and deposition of the mist of melt to give a growing body, there is first produced a knob containing fine-grained silicon primary crystals and intermetallic phases and this is formed by extrusion to give a tubular semi-finished part from which the cylinder liner is produced,
- during spraying, the melt is so finely atomized that the silicon primary crystals and intermetallic phases which form in the growing knob are obtained in grain sizes having the following dimensions, with the figures referring to the mean grain diameter in μm:
  Si primary crystals: from 2 to 15 μm,
  Al_2Cu phase: from 0.1 to 5.0 μm,
  Mg_2Si phase: from 2.0 to 10.0 μm,
- the exposure of the primary crystals and particles embedded at the surface out of the face of the cylinder liner, which has already been fine machined on its face, is carried out mechanically by a grinding or polishing process using at least one compliant shaped polishing or

grinding body and an abrasive, amorphous grinding or polishing medium containing particles of hard material whose particle size is less than or at most the same as the desired roughness.

7. A method according to Claim 6, wherein the mechanical exposure of the primary crystals and particles is carried out in the manner of a honing process using felt strips having an outer cylindrical shape and a slurry of particles of hard material

8. A method according to claim 7, wherein the said hard particles in the slurry are SiC particles in honing oil.

9. A method according to Claim 7 or 8, wherein the mechanical exposure of the primary crystals and particles is carried out with the felt strips being pressed against the contact point at a pressure of from 3 to 5 bar.

10. A method according to Claim 9, wherein the mechanical exposure of the primary crystals and particles is carried out at a pressure of 4 bar.

11. A method according to Claim 7, wherein the honing-like process for the mechanical exposure of the primary crystals and particles is carried out for from about 20 to 60 seconds

12. A method according to Claim 7, wherein the honing-like process for the mechanical exposure of the primary crystals and particles is carried out for about 40 seconds.

13. A method according to claim 6, wherein the silicon content of alloy types A and B is 25%, the magnesium content 1.2% and the coppper content 3.9%, and the grain size of the Si primary crystals is from 4.0 to 10.0 μm, the Al_2Cu phase from 0.8 to 1.8 μm, and the Mg_2Si phases from 2.5 to 4.5 μm.

14. A cylinder liner sealed into a reciprocating piston engine substantially as described herein with reference to and as illustrated in the accompanying drawings.

15. A method of forming a cylinder liner substantially as described herein with reference to the examples and as illustrated in the drawings.

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Patents Act 1977 **Examiner's report to the Comptroller under Section 17** **(The Search report)**	Application number GB 9520107.5
Relevant Technical Fields (i) UK Cl (Ed.N) C7A (ii) Int Cl (Ed.)	Search Examiner R B LUCK Date of completion of Search 18 DECEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1-5 AND 7-14

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